

Fractomechanoluminescence Produced During Impulsive Deformation of II-VI Semiconductor

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ABSTRACT

When II- VI semiconductor fracture charge dislocation moving near the tip of moving cracks produce intense electric field, which causes the band bending consequently, tunneling of electrons from field electron traps to the conduction band takes place, where by the radiative electron-hole recombination give rise to the luminescence characteristics of the recombination centres. When the crystal of II-VI semiconductor is fractured, impulsively initially the ML intensity increases with time, attains a maximum value I_m at a time t_m , and later on it decreases with time. I_m increase linearly with the ML intensity I_T initially increase linearly with v_o and later on it attains a saturation value of higher values of v_o .

Keywords: Fractomechanoluminescence, II-VI Semiconductor.

INTRODUCTION

During the fracture of semiconductors, charged dislocations move and also the piezoelectrification of the newly created surfaces may take place, as the crystals are piezoelectric. Thus, the ML excitation in II-VI semiconductors may occur due to the movement of charged dislocations and also due to the piezoelectrification in II-VI semiconductor.

The strength of electric field produced due to the movement of charged dislocations is higher as compared to the strength of the piezoelectric field. Thus, it has been proved that the major contribution to the fracto-ML in II-VI semiconductors is from the moving charged dislocation (Chandra 1998).

THEORY

The dislocation in II-VI semiconductors are charged, when a crystal

is fractured, then new charge surface S is created. The rate of generation of interacting filled electron traps can be expressed as

$$g_i = 2n_t r_t N_d \frac{ds}{dt} \quad (1)$$

The rate of creation of new surfaces is given by (Chandra *et al.* 2012)

$$\frac{ds}{dt} = bZ_0 V^{(m+m')} K_0 (n + n' - n'') \frac{v_0}{H} \exp[-\{(\xi + \gamma)t\}] \left[\frac{v_0}{H\xi} \{1 - \exp(-\xi t)\} \right]^{n+n'-n''-1} \quad (2)$$

where

b = a constant,

Z_0 = proportionality constant,

V = volume of crystals

m = an exponent, m' = an exponent,

K_0 = a constant, n = an exponent

n' = an exponent, n'' = an exponent,

v_0 = initial velocity of piston

H = thickness of the sample,

$\xi = \frac{1}{\tau_r}$ = rate-constant for the relaxation of moving piston

τ_r = time constant for the relaxation of moving piston

and, γ = rate constant for the decrease of average surface area produced by the movement of single crack

$$\frac{dn_i}{dt} = \frac{2n_t r_t N_d b Z_0 v_0 V K_0}{H} [\exp(-\xi t)] - \sigma n_i \quad (3)$$

where $\tau_i = 1/\sigma$ is the lifetime interacting filled electron traps.

If γ_1 , γ_2 and γ_3 are the rate constants for the transfer of electrons from conduction band to the hole centers, then we can write the following rate equation

$$\frac{d\Delta n}{dt} = g_c - (\gamma_1 + \gamma_2 + \gamma_3)\Delta n \text{ or,}$$

$$\frac{d\Delta n}{dt} = \frac{2n_t r_t N_d b Z_0 v_0 V K_0}{H} p_t [\exp(-\xi t)] - \gamma' \Delta n \quad (4)$$

where $\gamma' = (\gamma_1 + \gamma_2 + \gamma_3)$ and $1/\gamma' = \tau_e$, is the lifetime of electrons in the conduction band, and Δn is the change in the number of electrons in the conduction band at any time t .

If η_0 is the efficiency for the radiative electron hole recombinations, then the ML intensity may be expressed as

$$I = \frac{2\eta_0 n_t r_t N_d b Z_0 v_0 V K_0}{H(\gamma' - \xi)} p_t \gamma' [\exp(-\xi t) - \exp(-\gamma' t)] \quad (5)$$

By expanding the exponential terms in Eq. (5) and neglecting higher order terms, we get

$$I_r = \frac{2\eta_0 n_t r_t N_d b Z_0 v_0 V K_0}{H} p_t \gamma' t \quad (6)$$

Equation (6) indicates that after the impulsive deformation of the crystals, initially the ML intensity should increase linearly with time t .

Differentiating Eq. (5) and equating it to zero, the time t_m , at which the ML intensity will be maximum can be expressed as

$$t_m = \frac{1}{\gamma' - \xi} \ln\left(\frac{\gamma'}{\xi}\right) \quad (7)$$

where ξ is given by

$$\xi = \frac{v_0}{H[1 - \exp(-\delta v_0)]} \quad (8)$$

The ML intensity I_m corresponding to the peak of ML intensity versus time curve is given by

$$I_m = \frac{2\eta_0 n_t r_t N_d b Z_0 v_0 V K_0 p_t}{H} \quad (9)$$

$$I_T = 2\eta_0 n_t r_t N_d b Z_0 V K_0 p_t [1 - \exp(-\delta v_0)] \quad (10)$$

For $(\gamma' - \xi)t \gg 1$, Eq.(3.18) can be written as

$$I_{df} = I_m \exp\{-\xi(t - t_m)\} \quad (11)$$

The slow decay of ML in the post fracture region may be expressed by the following relation

$$I_{ds} = I_{dso} \exp\left[-\frac{(t-t'_c)}{\tau_s}\right] = I_{dso} \exp[-\chi(t - t'_c)] \quad (12)$$

where $\chi = \frac{1}{\tau_s}$, is the life time of electrons in shallow traps, t'_c is the time at which the prompt ML becomes negligible and I_{dso} is the ML intensity at $t = t'_c$. It is to be noted that slow decay of ML will be observed only when $\xi \gg \chi$.

EXPERIMENTAL SUPPORT TO THE PROPOSED THEORY

Since II –VI semiconductors exhibit intense ML during their plastic deformation, significant works have been done on the ML produced during their plastic deformation. Only limited studies have been made on the ML produced during fracture or cleavage of II – VI semiconductors.

Figs.1 and 2 show the time dependence of the transient ML intensity of ZnS:Mn (1000 ppm) and (Zn,Cd)S:Ag, Cl phosphors for different impact velocities. It

is seen that when the phosphors are fractured, initially the ML intensity increases with time, attains a peak value at a particular time, and then it decreases with further increase in the value of time, and after a particular time the ML intensity decreases slowly with time.

Figs. 3 and 4 show the plot of log I versus $(t-t_m)$ for ZnS:Mn and (Zn,Cd)S:Ag, Cl phosphors. It is seen from these figures that initially the ML intensity decreases at a fast rate, however, later on it decreases slowly. These decay characteristics of ML are in accordance with Eqs. (11) and (12). The values of t_m , ξ , χ , τ_r and τ_s are shown in table 3.2 for different velocities.

Fig. 5 shows the impact velocity dependence of the peak intensity I_m of the ML intensity versus time curve for ZnS:Mn crystals. This result is in accord with Eq. (9). Fig. 6 shows the impact velocity dependence of the total ML intensity I_T for ZnS:Mn crystals. The total ML intensity I_T initially increases with the impact velocity and then it tends to attain a saturation value. This result is in accord with Eq. (10).

The value of t_m decreases with increasing value of impact velocity. Fig. 7 shows that initially the plot increases linearly and then it tends to attain a saturation value for higher values of $\ln(1000/v_0)$. Thus, it seems that at low impact velocity of the piston the time t_m should be constant and independent of the impact velocity.

Fig.8 shows the dependence of I_m on area of (ZnS:Mn) crystals. It is seen that I_m increases linearly with the area of the crystals. Such result is expected from Eq. (9). Fig. 9 shows the dependence of total ML intensity I_T on the volume of (ZnS:Mn)

crystals. It is seen that I_T increases linearly with the volume of the crystals.

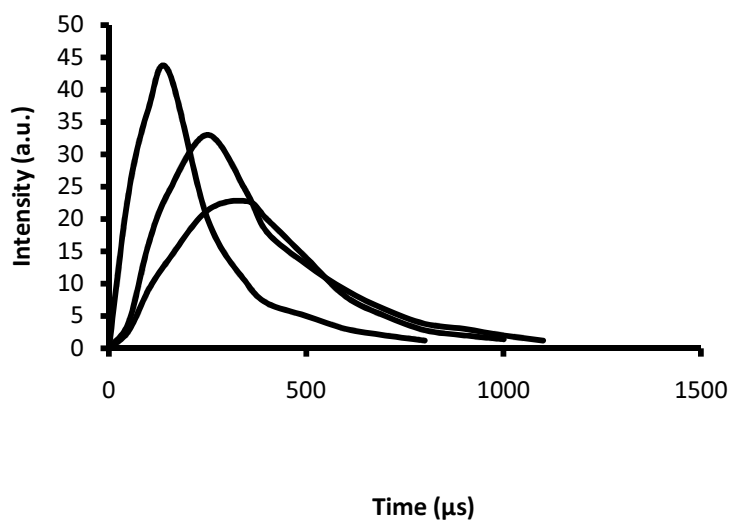


Fig.1 Time dependence of ML intensity of ZnS:Mn (1000 ppm) crystals (Curves I, II and III correspond to the impact velocity 186, 255 and 329 cm/s respectively) (Optoelectronics Lab., RDVV, Jabalpur)

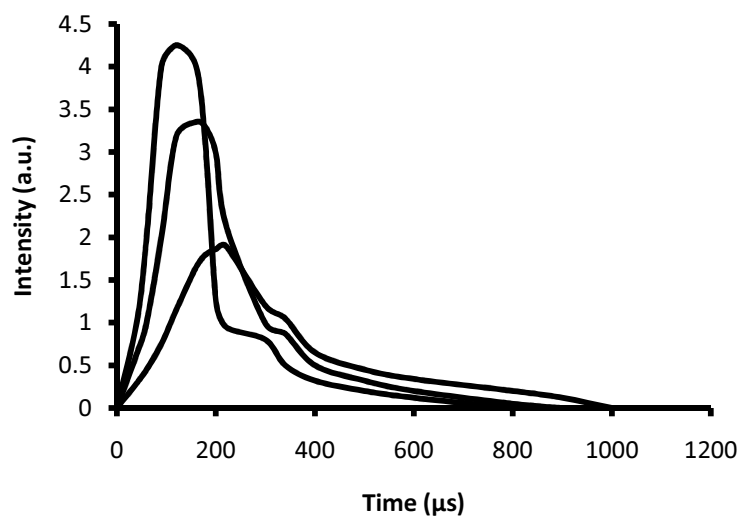


Fig.2 Time dependence of ML intensity of (Zn, Cd)S: Ag, Cl crystals (1000 ppm) (Curves I, II and III correspond to the impact velocity 155, 287 and 378 cm/s respectively) (Optoelectronics Lab., RDVV, Jabalpur).

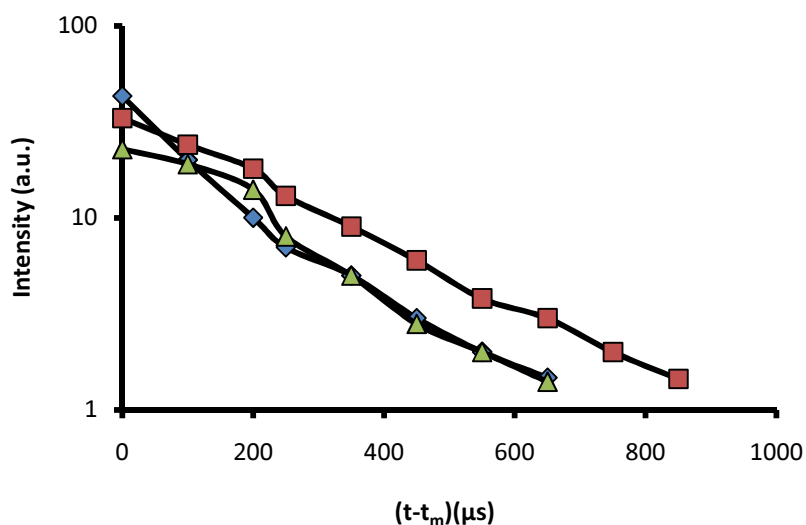


Fig. 3 Semilog plot of ML intensity versus $(t-t_m)$ for ZnS:Mn crystals (Curves I, II and III correspond to the impact velocity 186, 255 and 329 cm/s, respectively).

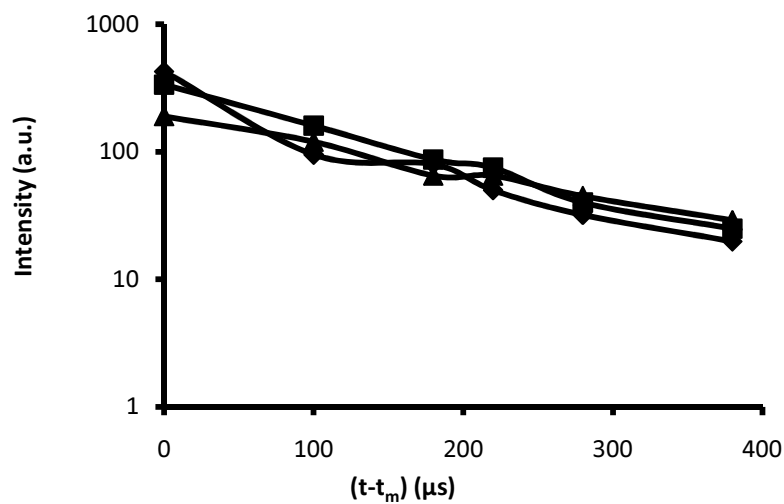


Fig. 4 Semilog plot of ML intensity versus $(t-t_m)$ for (Zn, Cd)S: Ag, Cl phosphors (Curves I, II and III correspond to the impact velocity 155, 287 and 378 cm/s, respectively).

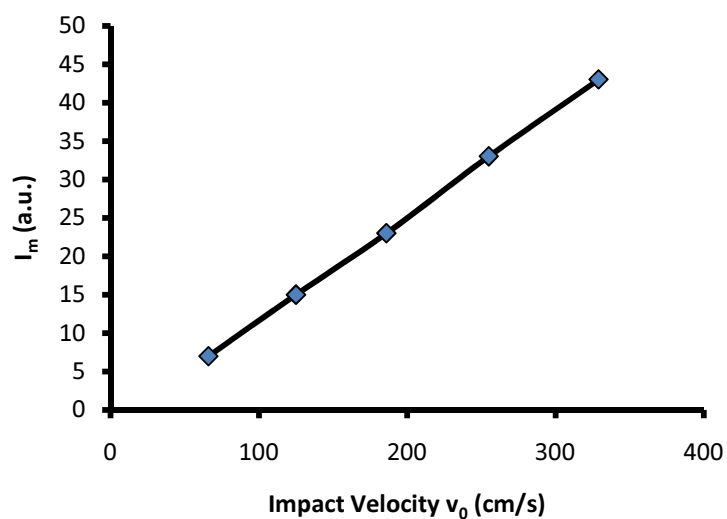


Fig. 5 Impact velocity dependence of the peak intensity I_m of ML intensity versus time curve for ZnS:Mn crystals (Optoelectronics Lab., RDVV, Jabalpur)

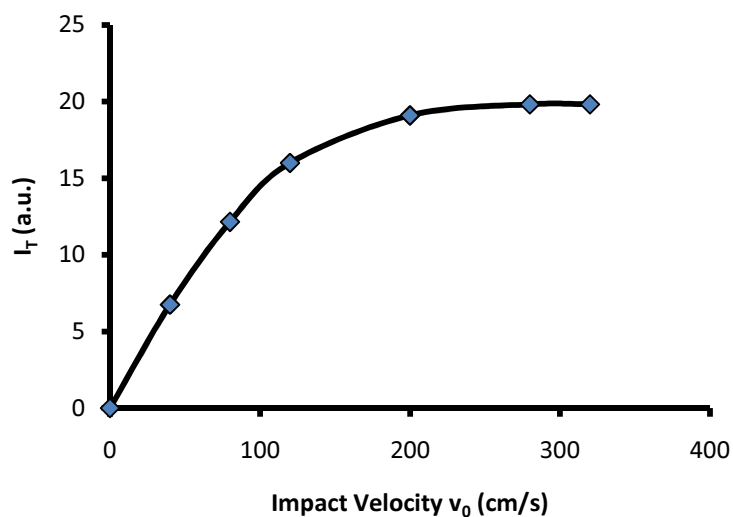


Fig. 6 Impact velocity dependence of the total ML intensity I_T for ZnS:Mn crystals (Optoelectronics Lab., RDVV, Jabalpur)

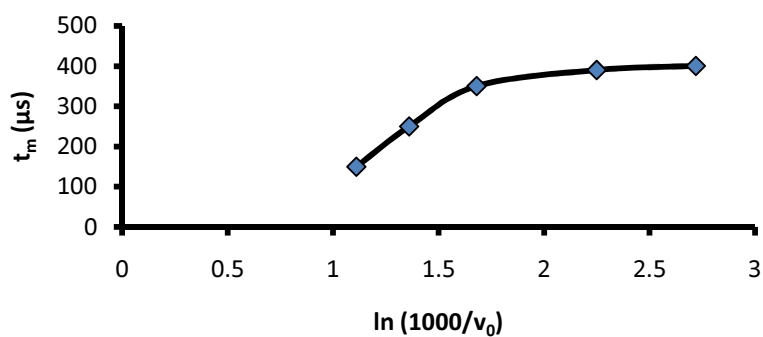


Fig. 7 Dependence of t_m on $\ln(1000/v_0)$ for ZnS:Mn crystals.

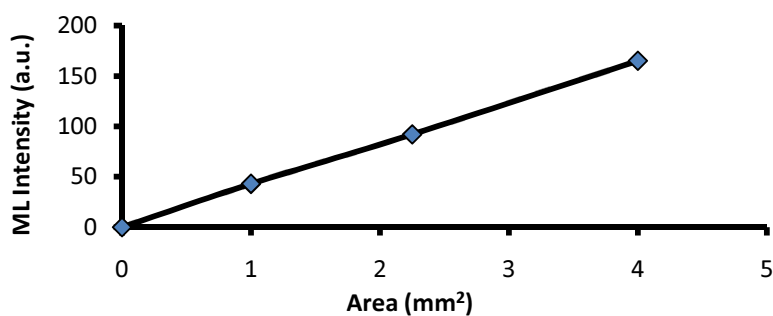


Fig. 8 Dependence of the peak intensity I_m on the area of cross section of the crystal for ZnS:Mn crystals (Optoelectronics Lab., RDVV, Jabalpur)

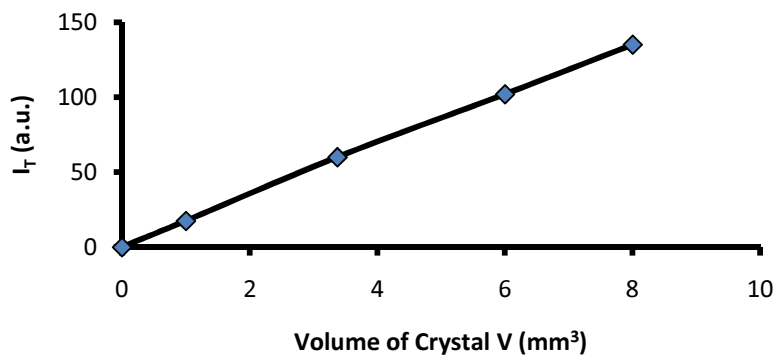


Fig. 9 Dependence of the total intensity I_T on the volume of the crystal for ZnS:Mn crystals (Optoelectronics Lab., RDVV, Jabalpur)

CONCLUSION

During the fracture of semiconductors, charged dislocations move and also the piezoelectrification of the newly created surfaces may take place, as the crystals are piezoelectric. Thus, the ML excitation in II-VI semiconductors may occur due to the movement of charged dislocations and also due to the piezoelectrification in II-VI semiconductor. The strength of electric field produced due to the movement of charged dislocations is higher as compared to the strength of the piezoelectric field. Thus, it has been proved that the major contribution to the fracto-ML in II-VI semiconductors is from the moving charged dislocation (Chandra 1998). When a crystal of a II-VI semiconductor is fractured,

impulsively then initially the ML intensity increases with time, attains a maximum value I_m at a time t_m , and later on it decreases with time. A good agreement is found between the theoretical and experimental results.

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